DISTRIBUTION OF BIOTA IN A STREAM POLLUTED BY ACID MINE-DRAINAGE[1]

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ABSTRACT

Acidic water draining from coal mines has severely restricted the diversity of biota inhabiting Roaring Creek, eastern West Virginia. Polluted reaches of the stream (median pH values ranging from 2.8 to 3.8) were inhabited by 3 to 12 genera of bottom-dwelling invertebrates and 10 to 19 species of periphytic algae. Invertebrates tolerant of the pollution included *Sialis* sp., *Chironomus plumosus* and other Chironomidae, dytiscid beetles, and *Ptilostomis* sp. Predominant among the tolerant periphyton were *Ulothrix tenerrima*, *Pinnularia termitina*, *Eunotia exigua*, and *Euglena mutabilis*. Six other species of algae were tolerant of the acid mine-pollution, but were never numerous.

Sections of Roaring Creek not severely polluted by acid drainage (pH medians of 4.5 or higher) supported diverse communities of 25 or more kinds of benthic animals and 27 or more species of periphytic algae. These stream reaches were inhibited by blackflies, crayfish, mayflies, stoneflies, and many species of caddisflies; these forms did not inhabit the more acidic stream reaches.

Because of the complex and varying chemical composition of the acid mine-drainage, and also because of possible physical influences, measurements of pH values in the stream seemed to provide the most reliable, as well as unique, index of the effects of acid mine-drainage on aquatic life.

INTRODUCTION

Water draining from coal mines is commonly polluted by sulfuric acid, acid salts, iron, aluminum, and other chemicals. These pollutants are formed when sulfitic materials, such as pyrite (FeS_2), contained in rock strata associated with coal seams, are exposed to air and water. On exposure to oxygen and water, aided by bacterial action (Parsons, 1957), the pyrite oxidizes and forms sulfuric acid and ferrous sulfate. Ferric hydroxide ("yellow-boy") is formed when the mine water mixes with alkaline surface waters.

Common among the chemical compounds in waters issuing from coal mines are sulfuric acid and the acid salts of iron, aluminum, zinc, lead, and copper. The complex mixtures of these chemicals present under these conditions may be toxic to animals in the concentrations commonly encountered (Parsons, 1957). This toxicity to aquatic animals is doubtless a function of more than one factor, including the concentrations of dissociated hydrogen and sulfate ions, increased osmotic pressure caused by high concentrations of mineral salts, increased carbon-dioxide tensions resulting from low pH values, oxygen reduction by the oxidation of metals, and possible synergism of metallic cations (Parsons, 1957). In addition, smothering blankets of iron salts deposited on stream beds reduce the numbers and possibly the variety of benthic invertebrates and algae.

Aquatic organisms respond in many ways to various types of pollution, the responses depending on chemical and physical factors, and upon the physiological characteristics of the organisms themselves. Waters that are not polluted are generally inhabited by great varieties of organisms, both tolerant of and sensitive to pollution. Conversely, polluted waters generally support only a few varieties of organisms, those that are tolerant of the pollution (these tolerant organisms may also inhabit non-polluted waters, along with pollution-sensitive organisms). For these reasons, studies comparing polluted waters with similar, non-polluted waters are useful in delineating the effects and extent of pollution. Studies by Lackey (1938 and 1939), Joseph (1953), Steinback (1966), and Parsons (1968)

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have demonstrated that streams polluted by acid mine-drainage generally are inhabited by only a few species of very tolerant plants and animals.

In Roaring Creek, a tributary of the Tygart Valley River near Elkins, West Virginia (fig. 1), high concentrations of chemical pollutants (Table 1) have produced a highly restrictive environment, capable of supporting only a specialized assemblage of tolerant plants and animals (Tables 2 and 3). In order to assess the effects of this pollution and to delineate the biological communities present in Roaring Creek prior to the instigation of extensive reclamation by the Federal Water Quality Administration (F.W.Q.A.), biological surveys were conducted. The results of these surveys constitute the basis for this paper.

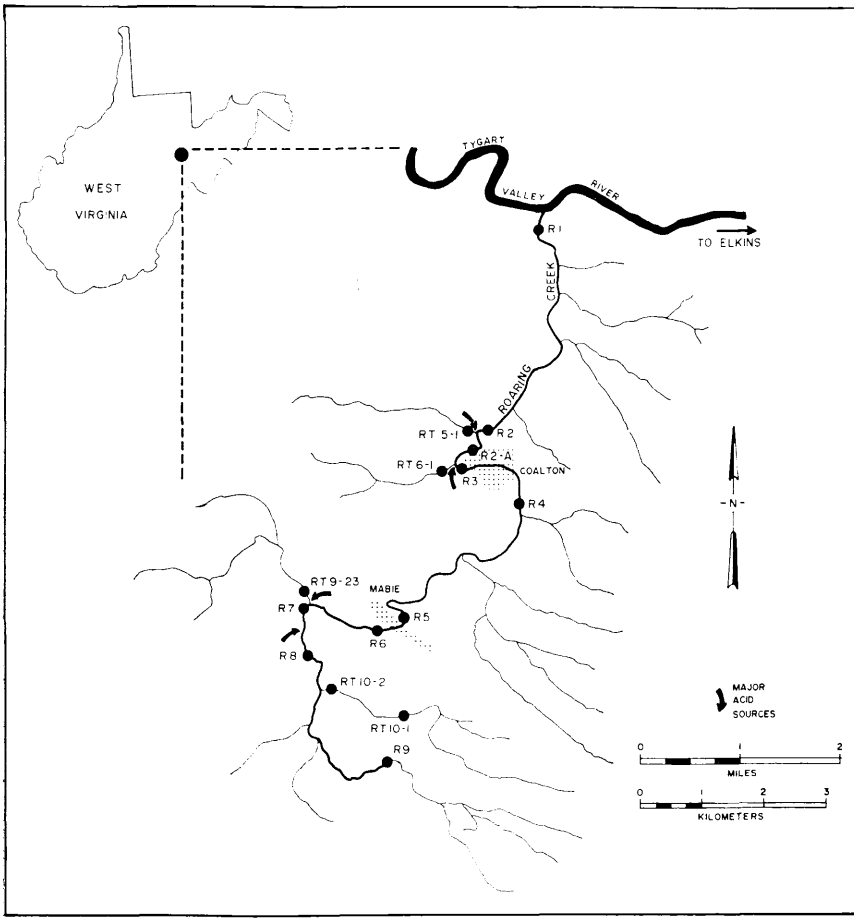

FIGURE 1. Map of Roaring Creek, West Virginia, showing locations of sampling stations.

Similar situations of limited biota inhabiting acid mine-waters have been reported from West Virginia and Indiana by Lackey (1938 and 1939), from Kentucky by Kinney (1964), from Ohio by Steinback (1966), and from Missouri by Campbell *et al.* (1965) and by Parsons (1968). Altogether approximately 5,890 miles of streams in the United States will not support fish because of acid mine-water pollution (Kinney, 1964). The problem is worldwide; severe habitat damage by acid mine-drainage has been reported in Australia, England, Japan, Korea, South Africa, and the U.S.S.R., and undoubtedly exists wherever coal is mined (Porges *et al.*, 1966).

TABLE 1

Summary of Roaring Creek Chemical Data, 19 March, 1964 to 29 June, 1966

	pH[1] (units)	Acidity (mg/l $CaCO_3$)	Total Iron (mg/l)	Sulfate (mg/l)	Total Hardness (mg/l $CaCO_3$)	Specific Conductance (μmho/cm)	Calcium (mg/l)	Aluminum (mg/l)	Ferrous Iron (mg/l)
Station R-1 (river mile 0.2)									
Maximum	4.1	318	19.0	520	381	1310	151	29.0	3.0
Minimum	2.7	19	0.8	29	25	110	19	0.0	0.5
Mean	3.3	104	5.4	166	97	528	71	10.6	1.3
σ[2]	——	68	3.3	193	67	274	47	7.4	0.6
N[3]	155	157	141	155	156	157	50	50	49
Station R-2 (river mile 3.1)									
Maximum	4.3	540	57.0	780	405	1630	245	30.0	10.0
Minimum	2.6	24	1.4	26	25	130	23	3.6	0.7
Mean	3.3	139	13.2	207	116	600	98	13.9	2.2
σ	——	106	10.5	152	87	359	67	7.9	1.4
N	161	163	151	161	162	162	50	50	49
Station R-2A (river mile 3.7)									
Maximum	4.2	660	72.0	750	422	1780	238	30.0	6.1
Minimum	2.6	18	1.2	28	24	106	20	2.9	0.7
Mean	3.3	130	12.7	198	112	577	85	13.0	2.7
σ	——	107	10.7	147	87	362	62	8.4	1.7
N	161	160	158	161	161	161	50	50	49
Station R-3 (river mile 4.0)									
Maximum	4.7	283	31.0	370	169	840	87	26.0	6.2
Minimum	3.0	8	0.2	28	20	65	13	1.2	0.3
Mean	3.8	46	2.0	85	55	248	36	6.3	1.4
σ	——	44	3.2	56	30	142	19	6.4	1.3
N	160	165	146	161	164	164	50	50	37
Station R-4 (river mile 5.1)									
Maximum	4.3	378	30.0	420	54	1000	89	34.0	6.5
Minimum	2.8	15	0.4	35	22	103	16	0.6	0.4
Mean	3.5	77	3.7	120	63	346	41	8.0	1.9
σ	——	73	5.3	84	36	227	20	7.2	1.6
N	70	70	70	70	69	70	49	49	34
Station R-5 (river mile 7.5)									
Maximum	4.5	535	64.0	590	277	1380	150	47.0	7.4
Minimum	2 8	10	0.2	24	20	75	17	3.0	0.5
Mean	3.6	75	4.9	125	75	335	53	11.1	1.9
σ	——	79	8.8	94	51	219	34	10.4	1.4
N	167	163	163	160	163	167	50	50	49
Station R-6 (river mile 8.1)									
Maximum	4.5	715	95.0	700	252	1580	150	49.0	12.0
Minimum	2.8	15	0.4	24	23	77	16	1.9	0.0
Mean	3.6	87	6.3	136	78	361	57	11.7	2.4
σ	——	96	11.3	112	55	257	36	10.8	2.2
N	127	128	111	126	127	128	49	48	48
Station R-7 (river mile 8.8)									
Maximum	4.9	1120	240.0	870	261	1780	129	81.0	150.0
Minimum	2.7	4	0.0	11	14	49	8	0.2	0.1
Mean	4.2	91	10.3	113	52	279	43	14.6	9.0
σ	——	173	29.7	155	49	339	33	16.6	25.6
N	119	119	108	116	119	119	49	49	46

TABLE 1—*Continued*

	pH[1] (units)	Acidity (mg/l $CaCO_3$)	Total Iron (mg/l)	Sulfate (mg/l	Total Hardness (mg/l $CaCO_3$)	Specific Conductance (µmho/cm)	Calcium (mg/l)	Aluminum (mg/l)	Ferrous Iron (mg/l)
Station R–8 (river mile 9.6)									
Maximum	5.1	50	2.4	220	92	332	24	1.8	1.2
Minimum	3.2	0	0.0	8	8	39	6	0.3	0.0
Mean	4.6	10	0.3	25	19	96	12	0.6	0.2
σ	——	10	0.4	27	8	65	9	0.3	0.2
N	60	60	58	58	60	60	40	40	40
Station R–9 (river mile 11.9)									
Maximum	6.6	70	47.0	76	38	380	18	17.0	0.9
Minimum	3.1	0	0.0	0	0	10	2	0.0	0.0
Mean	5.7	2	1.5	12	10	42	6	0.6	0.2
σ	——	10	5.0	19	7	45	3	2.5	0.2
N	107	110	107	106	107	106	44	44	30
Station RT5–1 (river mile 3.2–0.1)									
Maximum	4.1	968	180	1450	866	2270	397	44.0	35.0
Minimum	2.0	6	7	31	20	80	8	2.6	2.7
Mean	2.9	408	74	613	304	1243	238	13.4	8.1
σ	——	257	50	402	193	581	113	10.5	5.6
N	125	115	125	125	126	127	49	50	49
Station RT6–1 (river mile 3.9–0.2)									
Maximum	3.3	762	170.0	1050	688	1870	377	46	——
Minimum	2.2	158	10.6	330	184	980	110	19	——
Mean	2.8	509	76.2	745	327	1500	210	33	——
σ	——	87	23.2	129	84	167	52	5.1	——
N	126	127	125	126	126	125	49	50	49
Station RT9–23 (river mile 8.7–0.1)									
Maximum	4.4	276	18.0	420	320	975	138	24.0	——
Minimum	3.0	24	0.7	18	21	115	5	0.2	——
Mean	3.5	100	5.0	164	96	430	65	11.7	——
σ	——	62	3.2	98	65	215	39	7.3	——
N	119	120	107	119	119	120	46	46	43
Station RT10–2 (river mile 10.0–0.1)									
Maximum	5.8	36	1.0	32	26	260	18	1.4	0.1
Minimum	3.1	0	0.02	5	2	33	2	0	0
Mean	4.9	5	0.3	11	11	60	9	0.3	0.1
σ	——	7	0.6	6	5	46	4	0.3	0.0
N	22	22	22	22	20	22	16	18	4
Station RT10–1 (river mile 10.0–1.0)									
Maximum	6.8	74	1.6	32	36	548	39	1.4	0.6
Minimum	3.1	0	0	0	1	18	2	0	0
Mean	5.2	6	0.2	5	10	54	7	0.1	0.1
σ	——	8	0.3	5	14	56	5	0.1	0.1
N	155	157	150	143	144	156	78	91	30

[1]Median values of pH given, rather than mean.
[2]σ = Standard deviation.
[3]N = Number of analyses.

TABLE 2

Distribution of Benthic Animals in Roaring Creek and Selected Tributaries. June, 1964, to July, 1967.

	Mainstream										Tributaries				
Station	R-9	R-8	R-7	R-6	R-5	R-4	R-3	R-2A	R-2	R-1	RT10-1	RT10-2	RT9-23	RT6-1	RT5-1
River Mile	11.9	9.6	8.8	8.1	7.5	5.1	4.0	3.7	3.1	0.2	10.0-1.0	10.0-0.1	8.7-0.1	3.9-0.2	3.2-0.1
pH Range	3.1-6.6	3.2-5.1	2.7-4.1	2.8-4.1	2.7-4.5	2.8-4.3	3.0-4.2	2.4-4.0	2.6-4.3	2.7-4.1	3.1-6.2	3.1-5.8	3.0-4.4	2.2-3.3	2.0-4.1
pH Median	5.7	4.5	3.5	3.6	3.6	3.5	3.8	3.3	3.3	3.3	5.1	4.9	3.4	2.8	2.9
Insecta															
Ephemeroptera															
Ameletus sp.	x		x[1]								x	x			
Blasturus sp.												x			
Cloeon sp.	x														
Ephemerella sp.	x	x									x	x			
Hexagenia sp.	x	x										x			
Iron sp.	x										x				
Leptophlebia sp.												x			
Paraleptophlebia sp.	x	x									x				
Stenonema sp.	x	x										x			
Plecoptera															
Acroneuria sp.											x	x			
Allocapnia sp.	x										x	x			
Alloperla sp.	x	x									x				
Brachyptera sp.	x	x	x[1]				x				x	x			
Chloroperla sp.	x										x				
Isogenus sp.											x				
Isoperla sp.	x	x													
Leuctra sp.	x	x									x	x			
Nemoura sp.		x				x					x	x			
Paragnetina sp.	x														
Peltoperla sp.	x										x				
Trichoptera															
Cheumatopsyche sp.												x			
Dolophilodes sp.											x				
Glossoma sp.											x				
Hydropsyche sp.	x											x			
Neophylax sp.	x														
Polycentropus sp.		x													
Psycomyia sp.											x	x			
Ptilostomis sp.			x		x		x		x	x			x	x	x
Pycnopsyche sp.	x	x	x[1]				x					x			
Rhyacophyla sp.											x	x			

Diptera															
Simuliidae															
Simulium sp.	x	x									x	x			
Tipulidae															
Antocha sp.	x	x													
Eriocera sp.			x												
Hexatoma sp.		x													
Pedicia sp.	x	x				x	x								
Pseudolimnophila sp.												x			
Tipula sp.	x	x	x		x	x									
Ceratopogonidae					x		x	x		x					
Chironomidae															
Chironomus sp.			x	x	x	x	x	x	x	x	x		x	x	x
other*	x	x	x[1]		x	x	x	x	x	x	x	x	x	x	
Psychodidae															
Psychoda sp.								x							
Rhagionidae															
Atherix sp.		x													
Sarcophagidae															
Sarcophaga sp.	x														
Phoriade	x														
Culicidac												x			
Megaloptera															
Sialis sp.	x	x	x	x	x	x	x	x	x	x			x	x	x
Chauloides sp.		x		x	x		x				x	x		x	
Odonata		x	x				x								
Coleoptera															
Dytiscidae		x	x		x		x		x		x	x	x	x	
Hemiptera															
Corixidae	x									x	x				
Gerridae	x	x									x	x			
Lepidoptera															
Synclita sp.										x	x				
Annelida															
Tubificidae		x	x[1]				x				x	x			
Nematoda											x				
Isopoda															
Asellus sp.		x													
Decapoda															
Cambarus sp.	x	x									x	x			
Total Number of Taxa	30	26	7	3	8	6	12	5	5	7	28	25	5	6	3

[1]Collected only prior to June, 1965, when a new acid drainage started at station R-7. Not included in total.

*The following other genera of Chironomidae have been collected from Roaring Creek, but identifications were not made at each station: *Calopsectra*, *Cardiocladius*, *Carynoneura*, *Cricotopus*, *Pelopia*, *Pentaneura*, *Polypedilum*, *Psectrocladius*, *Spaniotoma*.

TABLE 3

Listribution of Periphyton in Roaring Creek and Selected Tributaries. June, 1964, to July, 1967.

	Mainstream										Tributaries				
Station	R–9	R–8	R–7	R–6	R–5	R–4	R–3	R–2A	R–2	R–1	RT10–1	RT10–2	RT9–23	RT6–1	RT5–1
River Mile	11.9	9.6	8.8	8.1	7.5	5.1	4.0	3.7	3.1	0.2	10.0–1.0	10.0–0.1	8.7–0.1	3.9–0.2	3.2–0.1
pH Range	3.1–6.6	3.2–5.1	2.7–4.1	2.8–4.1	2.7–4.5	2.8–4.3	3.0–4.2	2.4–4.0	2.6–4.3	2.7–4.1	3.1–6.2	3.1–5.8	3.0–4.4	2.2–3.3	2.0–4.1
pH Median	5.7	4.5	3.5	3.6	3.6	3.5	3.8	3.3	3.3	3.3	5.1	4.9	3.4	2.8	2.9
Division Chlorophyta															
Class Chlorophyceae															
Ulothrix tenerrima	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Microthamnion strictissimum	x	x	x	x	x	x	x	x	x	x		x	x		x
Microspora pachyderma	x	x	x	x	x	x	x		x	x	x	x	x		
Closterium acerosum	x	x		x	x	x	x	x	x	x			x		
Chlamydomonas sp.	x	x			x						x	x	x	x	x
Cosmarium spp.	x	x	x				x		x		x	x			
Staurastrum alternans	x			x	x		x	x	x						
Ochromonas sp.	x	x			x	x					x	x			
Scenedesmus abundans		x							x	x	x	x			
Zygogonium ericetorum		x			x	x					x	x			
Spirogyra sp.	x									x	x		x		
Protococcus viridis				x						x	x		x		
Cylindrocapsa geminella var. *minor*					x						x	x			
Cladophora sp.	x	x									x				
Ankistrodesmus falcatus		x									x		x		
Closteriopsis longissima							x			x			x		
Binuclearia tetrana		x		x											
Oocystis sp.		x									x				
Penium margaritaceum	x											x			
Gloeocystis gigas												x			
Hormidium subtile											x				
Stigeoclonium subtile							x								
Rhizoclonium sp.	x														
Pediastrum sp.												x			
Treubaria setigerum											x				
Dictyosphaerium pulchellum	x														
Division Chrysophyta															
Class Bacillariophyceae															
Eunotia exigua	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Pinnularia termitina	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Frustulia rhomboides var. *saxonica*		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Surirella ovata		x	x	x	x	x	x			x	x	x	x		
Gomphonema sp.	x	x	x		x		x				x	x	x	x	x
Achnanthes marginulata	x	x		x	x				x	x	x	x			
Navicula spp.	x	x	x							x	x	x			
Fragilaria sp.	x	x			x		x				x	x		x	
Cyclotella glomerata	x			x							x	x	x	x	
Tabellaria floculosa	x			x							x	x			
Meridion circulare	x							x	x	x					
Stephanodiscus hantzschii				x		x				x					
Diatoma hiemale	x										x	x			
Synedra acus	x			x								x			
Nitzschia hungarica	x		x		x										
Melosira ambigua	x										x				
Eunotia sudetica		x									x				
Pinnularia hilseana var. *hilseana*									x		x	x			
Melosira granulata									x						
Cocconeis diminuta							x								
Rhoicosphenia curvata						x									
Stauroneis anceps						x									
Cymbella sp.	x														
Nitzschia palea											x				
Denticula tenuis	x														
Surirella linearis var. *constricta*											x				
Surirella delicatissima											x				
Surirella angusta	x														
Division Euglenophyta															
Class Euglenophyceae															
Euglena mutabilis	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Trachylomonas sp.	x	x		x				x		x	x	x	x		x
Phacus sp.												x			
Division Cyanophyta															
Class Myxophyceae															
Oscillatoria sp.	x	x	x								x	x		x	x
Lyngbya sp.	x											x			
Anabaena sp.		x										x			
Chroococcus rufescens		x										x			
Spirulina nordstedtii												x			
Amphitrix janthina												x			
Porphyriosiphon notarissii				x											
Total Number of Taxa	33	27	13	19	18	14	16	10	14	19	35	34	17	10	10

MATERIALS AND METHODS

Biological investigations of 15 reaches of Roaring Creek and selected tributaries (fig. 1) were conducted during the winters, springs, summers, and falls from June 1964 to July 1967. Qualitative samples of bottom-dwelling invertebrates were collected by picking and scraping the bottoms of rocks and logs, and by agitating debris in a U. S. Standard No. 30 sieve. Benthos samples were preserved in 10% formalin solution. Qualitative samples of periphyton were collected by scraping rocks, twigs, and other substrates. Qualitative samples were examined live, then preserved in 5% formalin for detailed examination at high magnification. Diatoms were incinerated in nitric acid and potassium dichromate and permanently mounted on microscopic slides for examination at 1,175×.

Identification of most of the algae and benthic organisms were by personnel of the Federal Water Quality Administration at Cincinnati, using standard taxonomic keys. Some of the algae were identified by Drs. James B. Lackey (Chlorophyceae and Euglenophyceae) and C. Mervin Palmer (Chlorophyceae and Myxophyceae); Mr. Lee Tebo identified some of the Chironomidae. Representative specimens of the organisms collected were retained by the Federal Water Quality Administration staff at Cincinnati, Ohio, and are available for examination by interested investigators.

Chemical sampling was conducted on a weekly or biweekly basis, depending on station location. All chemical analyses, with the exception of those for metals, were performed by Federal Water Quality Administration personnel according to procedures delineated in "Standard Methods" (Orland, 1965). Metals were determined by atomic absorption using a Perkin-Elmer Model 303 instrument, operated according to manufacturer's instructions. Acidities were measured by titrating boiling samples to a measured pH (pH meter) of 8.3.

RESULTS

Benthos

Botton-dwelling animals are effective monitors of environmental conditions prevailing during the period of their residence. Some benthic invertebrates in Roaring Creek and its tributaries resisted the toxic effects of the acid mine-drainage and the deleterious effects of smothering blankets of deposits of iron salts better than did others (Table 2). However, benthic communities in polluted reaches of Roaring Creek (median pH values of less than 3.8) supported far less diversity than did those reaches less heavily polluted by mine drainage. Preferences for certain physical habitats influenced the distribution of pollution-tolerant species; for example, *Chironomus plumosus* was most abundant in reaches with a soft stream bed, and *Ptilostomis* sp. inhabited slack-water reaches. Harp and Campbell (1967) concluded that the distribution of acid-tolerant *Tendipes* (*Chironomus*) *plumosus* in coal-mine drainage was dependent on the presence of submerged leaf litter.

Head-water and tributary reaches of Roaring Creek not severely polluted by acid-mine drainage (median pH values of 4.5 and greater) supported relatively complex communities of benthic animals; for example, stations R–9 (pH 5.7), R–8 (pH 4.5), RT10–1 (pH 5.1), and RT10–2 (pH 4.9) were each inhabited by 25 or more species (Table 2). Conversely, stream reaches that received heavy loadings of acid supported fewer speceis of invertebrates; many of these species also inhabited non-polluted reaches. All main-stream reaches of Roaring Creek downstream from Station R–7 (river km 14.1), the reaches most heavily polluted, were inhabited by fewer than 13 invertebrate species, and the most severely polluted reaches were inhabited by less than 9 kinds of benthic invertebrates (fig. 2). Tributary streams very near mine sources (e.g. station RT5–1) were often uninhabited, and never supported more than 3 kinds of invertebrates.

A number of bottom-dwelling animals, including the alderfly (*Sialis* sp.), bloodworm midges (*Chironomus plumosus*) and other species of Chironomidae, and dytiscid beetles, tolerated very strong concentrations of acid mine-wastes (Table 2). These forms were locally abundant in severely polluted reaches; up to 16,675 individuals per m^2 of *Chironomus plumosus* were collected (with an Ekman dredge) from a swampy area having a median pH of 2.8. During the summer months, the caddisfly, *Ptilostomis* sp., could be found in slack-water reaches of all stations, regardless of the pH of the stream.

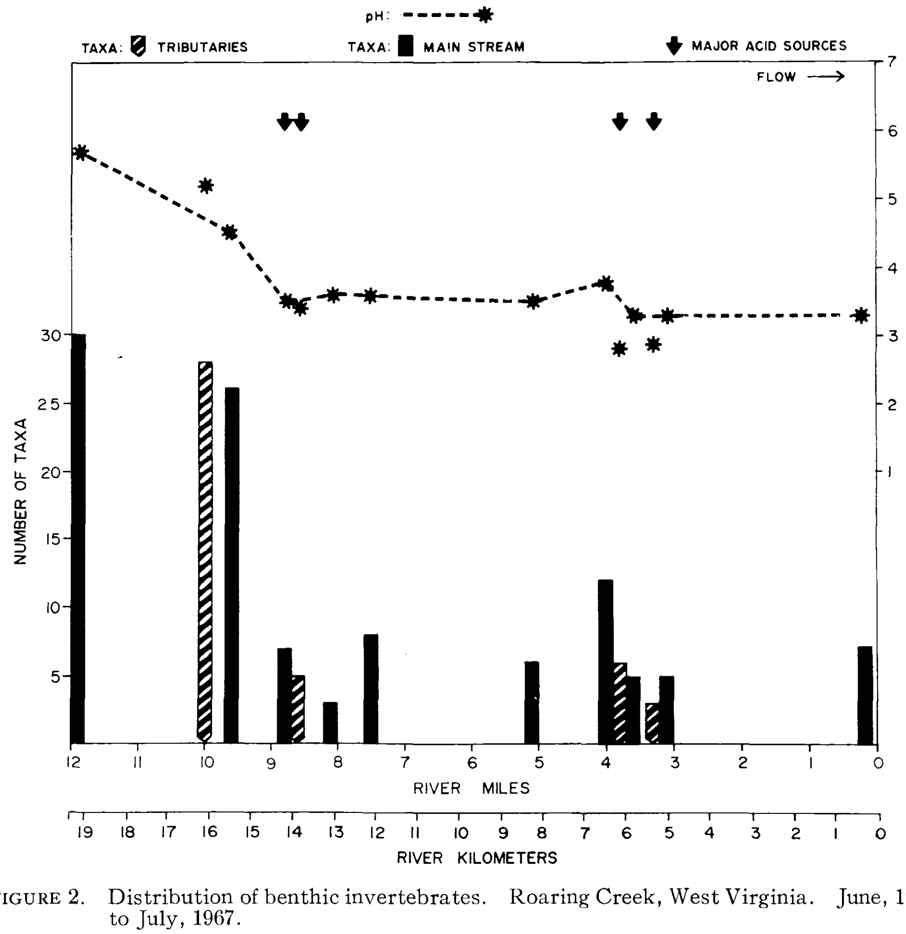

FIGURE 2. Distribution of benthic invertebrates. Roaring Creek, West Virginia. June, 1964, to July, 1967.

Most sensitive to acid pollution among benthic invertebrates of common occurrence in head-water and non-polluted reaches were blackflies, crayfish, mayflies, stoneflies, and many species of caddisflies (Table 2). All of these forms were repeatedly collected at stations with median pH values of 4.5 and higher, but were never obtained from reaches with median pH values below 4.5.

Periphyton

Periphytic communities in Roaring Creek responded to the effects of acid mine-pollution in a manner similar to that of the benthic invertebrates. Stream reaches with little or no acid pollution (pH 4.9 and higher) supported diverse periphytic communities consisting of 33 or more species (Table 3). Conversely, severely polluted stream reaches (pH 3.8 and lower) were inhabited by fewer than 20 species. The smothering effect of heavy blankets of ferric-hydroxide precipitates ($Fe(OH)_3$) had some influence on periphytic community dispersal. For ex- example, station R–7 (pH 3.5), with a stream bed heavily coated with $Fe(OH)_3$, supported only up to 13 periphyton species; stations R–6 (pH 3.6) and R–5 (pH 3.6), with clean stream beds, supported 19 and 18 species, respectively (fig. 3). Tributary streams near mine openings (e.g., RT5–1) supported no more than 10 species, and at times no more than 3 species could be found in such places.

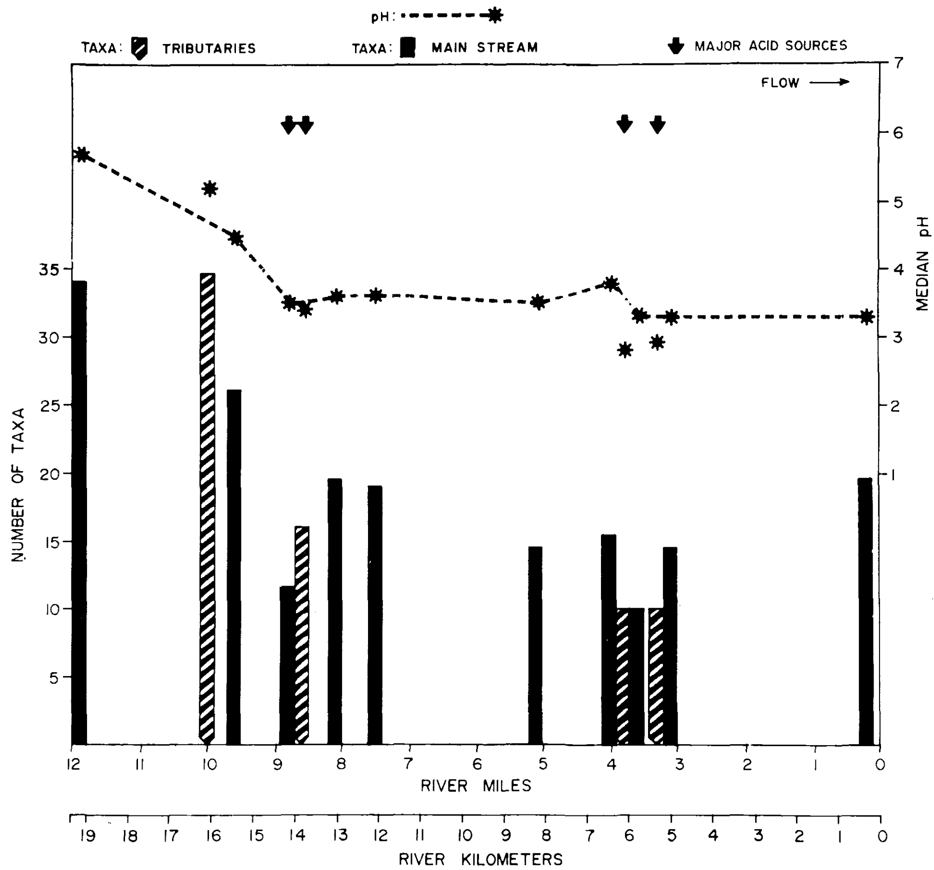

FIGURE 3. Distribution of periphyton. Roaring Creek, West Virginia. June, 1964, to July, 1967.

Among the 64 species of periphyton collected from Roaring Creek (Table 3), 10 species (*Ulothrix tenerrima*, *Microthamnion strictissimum*, *Microspora pachyderma*, *Closterium acerosum*, *Chlamydomonas* sp., *Eunotia exigua*, *Pinnularia termitina*, *Frustulia rhomboides*, *Surirella ovata*, and *Euglena mutabilis*) were particularly tolerant of severe acid mine-pollution. Only *Ulothrix tenerrima*, *Pinnularia termitina*, *Eunotia exigua*, and *Euglena mutabilis* were present in large numbers and this was always in the more acid reaches. Some tributary streams with major portions of their flow originating from mines contained flowing masses of *Ulothrix* sp. with some *Eunotia* sp. and *Pinnularia* sp. The beds of other tributary streams were coated with green slimes of hundreds of thousands of individuals of *Euglena* sp. per cm^2 (estimated by exposing glass slides in the stream for two to six weeks, then counting the attached algae), mixed with large numbers of *Pinnularia* sp. and *Eunotia* sp. Although other tolerant species of algae were found inhabiting the acidic reaches of Roaring Creek, they were never abundant.

Fish

Fish generally do not inhabit waters severely polluted by coal-mine drainage (Reppert, 1964; Lloyd and Jordan, 1964). Surveys of Roaring Creek by the U. S. Fish and Wildlife Service have revealed fish populations inhabiting only those reaches of the stream where the median pH was 4.9 or higher (R–9, pH 5.7; RT10–1, pH 5.1; RT10–2, pH 4.9; and two small non-polluted tributaries). Fish found in the Roaring Creek basin were brook trout (*Salvelinus fontinalis*), mottled sculpin (*Cottus bairdi*), blacknose dace (*Rhinichthys atratulus*), and creek chub (*Semotilus atromaculatus*). Attempts to plant the eggs of rainbow trout (*Salmo gairdneri*) have been unsuccessful (Burner, 1967).

DISCUSSION

The data presented in Tables 2 and 3 can be separated into two groups: 1) at stations with median pH values of 4.5 or higher, aquatic communities are composed of 25 or more genera of invertebrates and 27 or more species of algae, and 2) at stations with median pH values below 3.8, communities contain 12 or fewer invertebrate genera and 19 or fewer algal species. Regression analyses of these data (fig. 4 and 5) indicate that, although there is a gradual decrease in diversity with decreasing pH within each of the two groups, the change from one group to the other is not gradual. Rather, an abrupt decrease in diversity occurs between median pH 4.0 and median pH 4.4. This critical change probably occurs at pH 4.2, at which point all natural alkalinity (carbonates and bicarbonates) is lost from the water medium. Essentially all carbon dioxide in waters with pH values below 4.2 to 4.4 is in the form of free CO_2 (Hutchinson, 1957). Without available buffering capacity from carbonates and bicarbonates, many aquatic animals would be rapidly subjected to acidaemia.

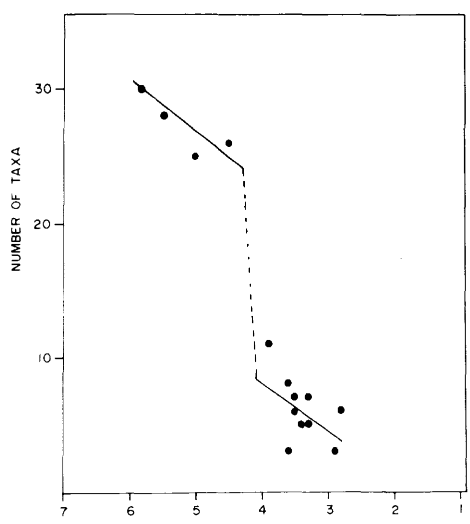

FIGURE 4. Regression of diversity of benthos against median pH.

In laboratory experiments, Lloyd and Jordan (1964) found that the 96-hour median tolerance limits (TL_m) of pH to rainbow trout were 4.18, 4.22, and 4.25 in waters with total hardnesses of 320, 40, and 12 mg/l, respectively. Carbon-dioxide levels of the blood of these fish indicated that death was due to acidaemia. High carbon-dioxide tension is undoubtedly of great importance in the distribution of fish in Roaring Creek, and may also influence the distribution of many species of invertebrates. High levels of free carbon dioxide may also influence the production of great masses of *Ulothrix tenerrima* and other tolerant algae near mine openings.

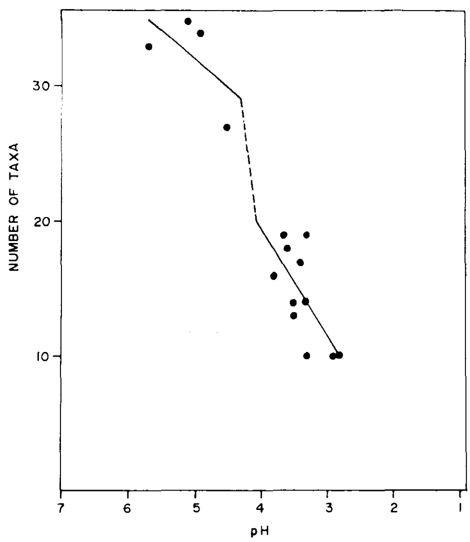

FIGURE 5. Regression of diversity of periphyton against median pH.

The direct toxicity of the sulfuric acid present in the waters of Roaring Creek probably influenced the distribution of plants and animals. Also, because Roaring Creek has low natural alkalinity (2 to 27 mg/l at control station RT10–1), small amounts of acidity caused severe lowering of the pH. In these waters, concentrations of acidity of 11 mg/l or greater (as $CaCO_3$) caused pH values to be lower than 4.5 (Table 1). Acidities were over 1500 mg/l (as $CaCO_3$) in the more severely polluted stream reaches, and averaged 50 to 150 mg/l in the main stream of Roaring Creek from station R–7 (river km 14.1) downstream to the mouth.

Additional sources of toxicity of acid mine-drainage were the sulfate and hydroxyl salts of iron and aluminum, and possibly of zinc, lead, and copper. The toxicity of all of these compounds varies greatly, depending upon the alkalinity and acidity of the water, upon the particular salt in question, and upon the organisms themselves. In Roaring Creek, from station R–7 downstream to the mouth, total iron concentrations averaged 3 to 13 mg/l and ranged as high as 240 mg/l, and aluminum concentrations averaged 7 to 16 mg/l and ranged as high as 82 mg/l. Sulfate concentrations averaged 80 to 210 mg/l and ranged as high as 870 mg/l. These salt concentrations are equal to or greater than the levels usually considered toxic to most species of fish (Parsons, 1957).

Because the waters of Roaring Creek constitute a complex and varying chemical environment, it is not possible to precisely assess the mode of their toxicity to aquatic biota; all of the factors mentioned, and possibly more, may be involved. However pH values were less variable than were the values of many other chemical constituents, and thus seem to provide a reliable index to the effects of acid coal-mine-drainage on aquatic life in this area.

SUMMARY

Acidic water draining from coal mines has restricted the diversity of biota inhabiting Roaring Creek, West Virginia. Severely polluted stream reaches (median pH 2.8 to 3.8) were inhabited by 3 to 12 genera of bottom-dwelling invertebrates and 10 to 19 species of periphytic algae. Stream reaches not severely polluted by acid mine-drainage (median pH 4.5 or higher) supported more diverse communities of 25 or more benthic invertebrate genera and 27 or more species of periphytic algae.

Regression analyses indicate that, although there are gradual decreases of diversity with decreasing pH from median pH 5.7 to 4.5 and from median pH 3.8 to 2.8, there are more abrupt diversity decreases at about pH 4.2, a point at which all natural alkalinity is lost from the water.

The factors influencing the distribution of invertebrates and algae in Roaring Creek are complex. Because each of these factors could independently limit the biota of waters polluted with acid mine-drainage, all must be considered collectively. Measurements of pH values appear to provide a reliable means of correlating water chemistry (pollution) with diversity of aquatic biota.

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